Chapter IV

Comparison of Experimental and Predicted Critical Unbraced Lengths

4.1 Comparison of Results

The evaluation of lateral-torsional buckling solutions and comparison with the experimental data are presented in the following tables. The comparisons of analytical solutions to the experimental values using the Tee Section Assumption are presented in Table 4.1. The differences in experimental lengths and the predicted lengths range from 46.1% to 29.4%. The lengths given by the analytical solutions are smaller than the experimental values, and therefore are conservative.

Table 4.1 Comparison of Results (Tee Assumption)

	Critical Unbraced Length (ft)			
	Experimental	Classical Solution	Load Location Term	Galambos
CB24x26	37.5	25.0	24.9	20.2
CB27x40	42.5	30.0	29.9	24.1

The comparisons of analytical solutions to the experimental values using the Full Section Assumption are presented in Table 4.2. The difference in experimental lengths and the predicted lengths range from 34.1% to 20%. The lengths given by the analytical solutions are smaller than the experimental values, and therefore are conservative.

Table 4.2 Comparison of Results (Full Section Assumption)

	Critical Unbraced Length (ft)			
	Experimental	Classical Solution	Load Location Term	Galambos
CB24x26	37.5	29.8	26.8	24.8
CB27x40	42.5	34.0	30.9	28.0

The comparisons of analytical solutions to the experimental values using the Average Section Assumption are presented in Table 4.3. The difference in experimental lengths and the predicted lengths range from 37.9% to 23.1%. The lengths given by the analytical solutions are smaller than the experimental values, and as for the other two methods, are conservative.

Table 4.3 Comparison of Results (Weighted Assumption)

	Critical Unbraced Length (ft)			
	Experimental	Classical Solution	Load Location Term	Galambos
CB24x26	37.5	28.4	25.5	23.3
CB27x40	42.5	32.7	29.8	26.5

From the calculations and comparison with test data it is evident that for the deep castellated beams tested, using the full section assumption and the classical lateral-torsional buckling solution in the calculations is most accurate. The difference between the experimental values and the calculated values may be attributed to assumptions made in the calculations. The effective length factors, k_y and k_ϕ, were assumed to be 1.0 in the classical lateral-torsional buckling solution and load location term methods. These lateral-torsional buckling solutions include the contribution of the web-to-column flange double angle connection on the lateral and torsional stability of the castellated beam through the effective length factors. The values assumed correspond to theoretical pinned conditions. The end connections used in the testing provide rotational restraint. Adjustments to the k_y and k_ϕ factors are examined in the following section.

4.2 Adjusted k_y and k_ϕ Factors

The following tables present critical unbraced length results for different k_y and k_ϕ factors in an attempt to better predict the strength of a castellated beam under erection loading. In Table 4.4, for comparison purposes the unbraced length values are calculated based on k_y and k_ϕ being 1.0.

Table 4.4 Assumption that k_y and k_ϕ Are Both 1.0

	Critical Unbraced Length (ft)			
	Experimental	Classical Solution	Load Location Term	Galambos
CB24x26	37.5	29.8	26.8	24.8
CB27x40	42.5	34.0	30.9	28.0

The assumption that k_y and k_ϕ are 1.0 is conservative when compared to the test results. The difference in experimental lengths and the evaluation of the predicted lengths range from 34.1% to 20% larger. This approach was deemed too conservative and the effective length factors were adjusted. If the connection is fully fixed then both factors are 0.5. However, this does not model the connection appropriately. In the connection, the torsional restraint is greater than the flexural restraint, due to the slotted holes and the plane of bending of the connection angle. The factors should reflect this fact.

In Table 4.5, the unbraced length values are calculated based on the assumption that k_y is 1.0 and the torsional factor, k_ϕ, is 0.5. The results of the classical lateral-torsional buckling solution and the addition of the load location term solution are presented; the Galambos formulation uses a different approach to the effective length factors and is presented later. For this assumption, the web-to-column flange double angle connection is assumed to be torsionally fixed. This assumption is supported by the fact that the thickness of the angles used in the connection and the thickness of the column flange are both greater than the thickness of the web of the castellated beam.

Table 4.5 Assumption k_y is 1.0 and k_ϕ is 0.5

	Critical Unbraced Length (ft)		
	Experimental	Classical Solution	Load Location Term
CB24x26	37.5	33.6	30.0
CB27x40	42.5	37.7	33.7

The difference in experimental lengths and the predicted lengths range from 20.7% to 10.4% larger. This approach better models the connection but is still conservative and the effective length factors are adjusted again.

In Table 4.6, the unbraced length values are calculated based on the assumption that k_y is 0.8 and the torsional factor, k_ϕ, is 0.5. In this assumption, the web-to-column flange double angle connection provides some flexural rigidity and full torsional rigidity. The difference in experimental values and the evaluation of the various solutions range from 15.5% to 4.8% larger.

Table 4.6 Asumption k_y is 0.8 and k_ϕ is 0.5

	Critical Unbraced Length (ft)		
	Experimental	Classical Solution	Load Location Term
CB24x26	37.5	35.7	31.9
CB27x40	42.5	40.1	35.9

A value of 0.5 for k_y was not used, because the web-to-column flange double angle connection is not a fixed-fixed connection.

The Galambos formulation uses a different approach to factoring in the contribution of the end restraints. In the derivation of this solution the effective length factors k_y and k_ϕ are combined into one factor, k. The results of the Galambos solution are presented in Table 4.7. The difference in experimental values and the prediction range from 22.8% larger for a value of k equal to 0.8 to –9.6% smaller for a value of k equal to 0.5. The assumption of k equal to 0.5 results in unconservative lengths.

Table 4.7 Application of Various k Values in the Galambos Formula

	Critical Unbraced Length (ft)		
	Experimental	k = 0.8	k = 0.5
CB24x26	37.5	29.2	41.1
CB27x40	42.5	32.8	46.0

The classical lateral-torsional buckling solution with effective length factors k_y as 0.8 and k_ϕ as 0.5 best model the test results and allows this solution to be used effectively.

4.3 Back Calculated k_y and k_ϕ Factors

To further investigate appropriate values of the k_y and k_ϕ effective length factors, the experimental critical unbraced lengths were used to back calculate k_ϕ for assumed values of k_y.

In Table 4.8, the torsional effective length factors calculated using the classical lateral-torsional buckling solution and the addition of the load location term solution with k_y equal to 1.0 and k_y equal to 0.8 are shown. The k_ϕ values from the classical solution with k_y equal to 0.8 are reasonably close to 0.5 as was determined in Section 4.2.

Table 4.8 Evaluation where k_y is 1.0 or 0.8 and k_ϕ is Calculated

	Torsional Effective Length Factor, k_ϕ with $k_y = 1.0$		Torsional Effective Length Factor, k_ϕ with $k_y = 0.8$	
	Classical Solution	Load Location Term	Classical Solution	Load Location Term
CB24x26	0.30	0.18	0.40	0.23
CB27x40	0.28	0.16	0.37	0.21

In Table 4.9, the unbraced length from the experimental data was entered into the Galambos formula and the effective length factor calculated. The results from the Galambos formulation are reasonable. However, with the single effective length factor this method does not allow the connection to be modeled as precisely as the solution with two effective length factors.

Table 4.9 L_b is Entered from Test Results and k is Calculated

	Torsional Effective Length Factor, k_ϕ
	Galambos
CB24x26	0.57
CB27x40	0.56

4.3 Conclusions

From the evaluation of the lateral-torsional buckling solutions and comparison with the test results, it is evident that there is a significant contribution from the web-to-column flange double angle connection on the stability of the castellated beam. The evaluation of the classical lateral-torsional buckling solution using k_y equal to 0.8 and k_ϕ equal to 0.5 yielded an unbraced length that is within 4.8% (larger) for the CB24x26 section and 5.6% (larger) for the CB27x40 section than the experimental length. The assumptions made in these calculations are the best representation of the contribution of the web-to-column flange double angle connection on the lateral stiffness and torsional rigidity of the castellated beam and are recommended for design.